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Bisphenol A and child and youth behaviour: Canadian Health Measures Survey 2007 to 2011

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Abstract

Background: Bisphenol A (BPA) is a synthetic industrial chemical commonly used in consumer products. Results from the Canadian Heath Measures Survey (CHMS) indicate that more than 90% of children and youth aged 6 to 19 have detectable levels of urinary BPA. Childhood concentration levels of BPA have been linked with negative behavioural outcomes.

Methods: The data are from the first two cycles (2007 to 2009 and 2009 to 2011) of the CHMS, which collected biomonitoring indicators via spot blood and urine samples. Behavioural outcomes—hyperactivity/inattention, emotional symptoms, conduct problems, peer problems, and prosocial behaviour—were assessed with Goodman's *Strengths and Difficulties Questionnaire*. Geometric mean urinary BPA concentration was examined overall and by demographic and socioeconomic correlates. Six multiple logistic regression analyses were conducted to investigate associations between childhood BPA concentrations and risk status for each outcome.

Results: Children aged 6 to 8 had higher BPA concentrations than did older children and youth. Concentrations were significantly higher among children and youth exposed to second-hand smoke every day or almost every day and those in low or lower-middle income households. Higher BPA concentrations were associated with hyperactivity among girls and lower prosocial behaviour among boys.

Interpretation: These findings suggest an association between urinary BPA concentration and children's behavioural outcomes.

Keywords: Biomonitoring, detection, environmental exposure, hyperactivity, prosocial behavior, tobacco smoke

Bisphenol A (BPA) is a synthetic industrial chemical commonly used in consumer products such as re-usable bottles, toys and plastic dinnerware, epoxy resins that coat the interior of metal food containers, and dental composites and sealants.[1] Biomonitoring results from the Canadian Heath Measures Survey (CHMS) indicate widespread exposure among children and youth, with 93% of 6- to 11-year-olds and 94% of 12- to 19-year-olds having detectable levels of urinary BPA.[2] Although evidence is inconclusive,[3,4] even low levels of BPA exposure may be associated with negative health outcomes for children, including behavioural problems.[4]

A number of demographic and socioeconomic risk factors have been related to urinary BPA concentrations. In general, males (compared with females)[5] and individuals in lower income households (compared with higher)[6,7] have higher concentrations. Arbuckle et al.[8] reported significantly higher urinary BPA among pregnant women with low income and low education, and among mothers who reported that they had smoked during their pregnancy. Other research, however, did not find education to be associated with urinary BPA concentrations.[6,9] Individuals of Mexican-American and non-Hispanic white ethnicity were reported to have lower urinary BPA than non-Hispanic Blacks.[5] Obesity has been linked to BPA levels,[7,10,11] in particular, for non-Hispanic white boys (with no significant associations for Hispanic boys or for girls of either ethnic group).

Research has demonstrated links between prenatal BPA exposure and behavioural outcomes.[12] However, the sex of the child may moderate associations between in-utero BPA exposure and behavioural difficulties.[9,13-15]

Childhood (environmental) concentrations of BPA have also been linked with behavioural outcomes, including anxiety, depression, hyperactivity, and inattention.[9] Even low levels may have an effect, as evidenced by non-linear associations between BPA and externalizing problems.[4] Exposure to dental composites (of which BPA is a common component) has also been associated with psychosocial outcomes in children aged 6 to 10, including higher emotional symptoms and total problem behaviours.[16] Maserejian et al.[16] speculated that BPA may be released through degradation of dental composites over time, resulting in long-term exposure, but more recent evidence suggests that this degradation is minimal and well below recommended daily levels.[17]

Associations between childhood BPA exposure and behaviour may differ by sex. Harley et al.[9] reported that childhood BPA exposure was linked with mother-reported externalizing behaviour (for example, conduct problems) only for girls; no interactions with sex were found for teacher-reported outcomes. Other studies did not find significant associations between BPA concentrations and behavioural problems to be moderated by child sex,[4,18] although small sample sizes may have impeded detection of significant interactions.[18]

Because research on relationships between exposure to BPA and child behaviour is in its early stages, examination of different datasets and populations is necessary.[14,19] The current study uses CHMS data to investigate associations between urinary BPA concentrations and behavioural outcomes for children aged 6 to 11 and youth aged 12 to 17, including differences by sex.

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Methods

Data source

The data are from the first two cycles (2007 to 2009 and 2009 to 2011) of the CHMS, a direct health measures survey that targets household residents aged 6 to 79. It is conducted by Statistics Canada in collaboration with the Public Health Agency of Canada and Health Canada to produce estimates representative of the national population. Ethics approval for the survey was obtained from Health Canada's Research Ethics Board.[20]

The CHMS involves an in-person interview to gather sociodemographic, health and lifestyle information, and a subsequent visit to a mobile examination centre for direct physical measures, including spot blood and urine samples. From March 2007 through February 2009, cycle 1 collected information from 5,604 respondents aged 6 to 79 living in private dwellings in 15 locations across Canada. From August 2009 through November 2011, cycle 2 collected information from 6,395 respondents aged 3 to 79 living in private dwellings in 18 locations. People in the territories, on Indian reserves and in other Aboriginal settlements in the provinces, full-time members of the Canadian Forces, the institutionalized population, and residents of some remote regions were excluded. Details about the sampling frame and data collection are available elsewhere.[21]

The present study pooled data from cycles 1 and 2 to increase the sample size, and thereby, increase the precision of estimates. The combined response rates (household, person, and direct measures level) were 51.7% for cycle 1 and 55.5% for cycle 2. The current analysis pertains to 2,802 respondents aged 6 to 17 at the time of the interview (cycle 1 or 2), weighted to represent about 4.7 million children and youth. A total of 2,730 of these respondents provided a spot midstream urine sample; detectable levels of BPA were found for 2,554.

Biomarkers

Standardized procedures were followed for the collection of blood and urine samples.[22] Urinary BPA concentrations below the limit of detection (LOD = 0.2µg/L) were imputed to half of the detectable limit (LOD/2 = .1).[23] Because the half-life of BPA is relatively short[24] and spot urine samples are only an approximation of daily exposure,[25] time of day of urine collection was included as a control variable in this study. To control for urine dilution, urinary creatinine concentration was measured and included as a covariate in the analyses. The analyses also controlled for blood lead levels, which have been associated with child health outcomes[26] (all respondents had a blood lead concentration above the limit of detection).

Behavioural outcomes

Behavioural outcomes were assessed with Goodman's *Strengths and Difficulties Questionnaire*,[27] a standardized, validated measure of internalizing and externalizing difficulties among children, which has been associated with adult mental health outcomes.[28,29] For all children and youth, parents reported 25 behavioural characteristics, scored on a three-point scale: 0 (not true), 1 (somewhat true), or 2 (certainly true). Items were summed to create five subscale scores (five items each): hyperactivity/inattention (for example, "restless, cannot stay still for long," Cronbach $\alpha = .79$); emotional symptoms (for example, "often seems worried," $\alpha = .66$); conduct problems (for example, "often fights with other children/youth or bullies them," $\alpha = .62$); peer problems (for example, "prefers to play alone," $\alpha = .59$); and prosocial behaviour (for example, "considerate of other people's feelings," $\alpha = .64$). Internal consistency scores were similar to parent-rated scores obtained by Goodman.[28] A score for total behavioural problems was created by summing four of the five subscales (excluding prosocial behaviour). High (at-risk) levels of behavioural problems were first examined using cut-points established by Goodman[28] as well as sex-specific norms.[30] Owing to small sample sizes for low prosocial behaviour, sex-specific 90th percentile values were also determined using the CHMS data to create sample-/Canadian-specific cut-points (Table 1). These cut-points were similar (within 1 unit for each subscale) but not identical to those established by Goodman,[28] and were used in the current study to identify at-risk groups for behavioural problems (conduct problems: boys ≥ 3, girls ≥ 3; emotional symptoms: boys ≥ 4, girls ≥ 5; hyperactivity: boys ≥ 7, girls ≥ 6; prosocial behaviour: boys ≤ 7, girls ≤ 8; peer problems: boys ≥ 4, girls ≥ 2; total behavioural problems: boys ≥ 15, girls ≥ 13).

Covariates

Several demographic and socioeconomic characteristics were explored as covariates, based on research on neurotoxin exposure and child outcomes,[5,6,31] and on known associations between these correlates and children's behavioural problems.[32] Parents of children aged 6 to 11 and youth aged 12 to 17 reported age at the time of the interview (6 to 8, 9 to 11, 12 to 14, and 15 to 17), sex, and ethnicity. Because of relatively small numbers in racial groups other than white, all other ethnicity groups were collapsed into non-white.

An indicator of exposure to second-hand smoke was created by combining responses to two questions: whether someone smoked in the home, and/or whether the child was exposed to second-hand smoke outside the home every day or almost every day versus once a week or less.

Household income was reported in dollars (missing values were imputed[33]) and categorized into three groups—low and lower-middle, upper-middle, and highest—based on total household income and the number of people in the household. The lowest income group

consisted of one- or two-person households with a total annual income of less than $30,000; three- or four-person households with less than $40,000; and five-or-more-person households with less than $60,000. The highest income category was one- or two-person households with a total annual income of at least $60,000, and three-or-more-person households with at least $80,000.

The highest level of education in the household was dichotomized as secondary school graduation or less versus at least some postsecondary education.

Interviewer-measured height and weight were used to calculate body mass index (BMI), which was collapsed into three categories: neither overweight nor obese, overweight, and obese.[33] For children aged 11 or younger, the parent or guardian indicated birthweight, age of the mother when the child was born, and if the child's mother had smoked during pregnancy.

Analysis

Geometric mean urinary BPA concentration was examined overall and by the demographic and socioeconomic correlates. To estimate adjusted least square geometric mean (LSGM) BPA concentrations, separate regressions were run for ethnicity, household income, exposure to second-hand smoke, household education, and BMI, controlling for child age and sex, time of day of urine collection, and urinary creatinine.

Spearman correlations were examined to identify possible associations between BPA and children's risk for behavioural problems.

Six multiple logistic regression analyses were conducted to investigate associations between BPA concentration and risk status for each outcome (conduct problems, emotion/anxiety, hyperactivity/inattention, peer problems, low prosocial behaviour, and total behavioural problems). In the first step, preliminary models examined associations between urinary BPA concentration and child behavioural outcomes, controlling for blood lead, urinary creatinine, and time of day of urine collection (results available on request).

In a second set of models, the sociodemographic covariates were added as controls. Because concentrations of lead and BPA were not normally distributed, log transformations (base 2) were applied.[18,34] Significant results indicate the change in the odds of being at risk for the behavioural outcome associated with a twofold increase in urinary BPA concentration. Urinary creatinine was included as a covariate (rather than specifically adjusting BPA for creatinine) to account for possible age-, race- and sex-related differences in creatinine excretion.[35,36] Time of urine collection (morning, afternoon or evening) was also included to adjust for fluctuations in BPA levels throughout the day.[2] A final set of regression models was fitted for boys and girls separately.

The literature has suggested possible non-linear associations between childhood BPA concentration and behavioural outcomes.[4] Therefore, quartiles of exposure (based on the 25th, 50th, and 75th percentiles) were explored in subsequent models. Results were consistent with the linear models, and thus, are not presented.

Table 1
Selected characteristics of sample, household population aged 6 to 17, Canada, 2007/2009 and 2009/2011 (combined)

Characteristics	Weighted %	95% confidence interval from	to
Age group			
6 to 8	21.6	19.4	23.9
9 to 11	24.7	22.5	27.2
12 to 14	24.9	22.5	27.5
15 to 17	28.8	26.5	31.2
Sex			
Male	52.4	51.3	53.5
Female	47.6	46.5	48.7
Ethnicity			
White	75.1	64.0	83.7
Non-white	24.9	16.3	36.0
Exposure to second-hand smoke			
Once a week or less	79.9	75.9	83.3
Every day or almost every day	20.1	16.7	24.1
Household income			
Low/Lower-middle	23.0	19.7	26.8
Upper-middle	26.7	22.8	31.1
Highest	50.3	44.9	55.6
Household education			
Secondary school graduation or less	13.8	10.9	17.3
At least some postsecondary	86.2	82.7	89.1
Body Mass Index			
Neither overweight nor obese	73.3	69.5	76.9
Overweight	13.9	11.4	16.8
Obese	12.8	10.9	14.9
Behavioural outcomes			
Total behavioural problems	11.4	9.2	14.0
Conduct problems	12.8	11.1	14.7
Emotion/Anxiety	14.3	12.1	16.9
Hyperactivity	12.6	10.2	15.5
Low prosocial behaviour	15.6	13.4	18.2
Peer problems	15.4	13.4	17.6

Source: 2007/2009 and 2009/2011 Canadian Health Measures Survey (combined).

Survey weights and appropriate degrees of freedom were applied to account for the complex survey design. Bootstrap weights were applied using SUDAAN 11.0 to account for underestimation of standard errors.[37]

Results

Descriptive characteristics of the sample are provided in Table 1. The sample was divided almost evenly between boys and girls. About half were in households in the highest income category. The sample was predominantly white (75%). Most lived in households where one or more members had at least some postsecondary education (86%). About one-quarter were overweight or obese. One in five (20%) was exposed to smoke in the home or outside the home every day or almost every day. Based on data-driven cut-points, 13% of children and youth in the sample were at risk for conduct problems, 14% for emotion/anxiety, 13% for hyperactivity, 16% for low prosocial behaviour, and 15% for peer problems. Overall, 11% scored above the threshold for total behavioural problems.

The mean urinary BPA concentration of the sample was 1.3 µg/L, with values ranging from .10 µg/L to 420 µg/L.

Table 2
Geometric means of urinary BPA concentrations, by selected characteristics, household population aged 6 to 17, Canada, 2007/2009 and 2009/2011 (combined)

Characteristics	Geometric mean (µg/L)	95% confidence interval	
		from	to
Total[3]	**1.3**	**1.1**	**1.4**
Age group[3]			
6 to 8[†]	1.8	1.6	2.1
9 to 11	1.4*	1.2	1.7
12 to 14	1.2***	1.0	1.4
15 to 17	0.9***	0.8	1.1
Sex[3]			
Male[†]	1.2	1.1	1.4
Female	1.3	1.2	1.5
Time of urine collection[3]			
Morning[†]	1.1	1.0	1.3
Afternoon	1.5***	1.3	1.7
Evening	1.4	1.0	1.7
Ethnicity[3]			
White[†]	1.3	1.2	1.5
Non-white	1.3	1.0	1.6
Exposure to second-hand smoke[3]			
Once a week or less[†]	1.2	1.1	1.4
Every day or almost every day	1.6**	1.4	2.0
Household income[3]			
Low/Lower-middle	1.7***	1.4	2.0
Upper-middle	1.2	1.0	1.4
Highest[†]	1.2	1.1	1.4
Household education[3]			
Secondary school graduation or less	1.3	1.0	1.6
At least some postsecondary[†]	1.3	1.1	1.5
Body Mass Index[3]			
Neither overweight nor obese[†]	1.3	1.2	1.5
Overweight	1.3	1.0	1.7
Obese	1.2	1.0	1.4

* significantly different from reference group ($p < 0.05$)
** significantly different from reference group ($p < 0.01$)
*** significantly different from reference group ($p < 0.001$)
† reference group
‡ geometric mean adjusted for creatinine
§ least squares geometric mean adjusted for age, sex, creatinine, time of urine collection
Source: 2007/2009 and 2009/2011 Canadian Health Measures Survey (combined).

When creatinine was taken into account, 6- to 8-year-olds had higher BPA concentrations than did older children and youth (Table 2). Controlling for age, sex, creatinine, and time of day of urine collection, BPA concentrations were significantly higher among children and youth exposed to second-hand smoke every day or almost every day. As well, children and youth in low and lower-middle income households had significantly higher BPA concentrations than did those in the highest income households. However, BPA concentrations did not differ by sex, ethnicity, level of education in the household, or BMI.

Correlation analyses indicated small but statistically significant associations between BPA concentration and most behavioural outcomes: total behavioural problems ($r = .07$, $p \leq .001$); conduct disorder ($r = .09$, $p \leq .001$); emotion/anxiety ($r = .05$, $p = .02$); hyperactivity ($r = .05$, $p \leq .01$); and low prosocial behaviour ($r = .04$, $p = .03$). In a preliminary model that controlled for urinary creatinine, time of urine collection, and blood lead, higher BPA concentrations were associated with increased odds of hyperactivity and of low prosocial behaviour. Analyses that controlled for continuous age (years), sex, ethnicity, smoking exposure, household income and education, BMI, time of day, urinary creatinine, and blood lead demonstrated associations between BPA concentration and low prosocial behaviour (Table 3). A marginally significant ($p = .06$) association with hyperactivity also emerged.

Further analyses indicated a significant interaction between sex and BPA for prosocial behaviour ($p \leq .05$) and a trend for hyperactivity ($p = .10$). Separate analyses for prosocial behaviour and hyperactivity for boys and girls found BPA concentration to be significantly associated with increased odds of hyperactivity for girls, but not for boys, and increased odds of low prosocial behaviour for boys, but not for girls (Table 3). With each twofold increase in urinary BPA concentration, girls had 28% greater odds of hyperactivity, and boys had 24% greater odds of low prosocial behaviour.

Table 3
Adjusted odds ratios relating BPA concentration to behavioural outcomes, by sex, household population aged 6 to 17, Canada, 2007/2009 and 2009/2011 (combined)

	Total			Male			Female		
	Adjusted odds ratio	95% confidence interval		Adjusted odds ratio	95% confidence interval		Adjusted odds ratio	95% confidence interval	
Behavioural outcomes		from	to		from	to		from	to
Total behavioural probems	1.07	0.93	1.24	1.00	0.79	1.26	1.18	0.94	1.48
Conduct problems	1.09	0.93	1.28	1.14	0.93	1.40	1.02	0.83	1.25
Emotion/Anxiety	1.02	0.85	1.23	0.98	0.79	1.23	1.05	0.83	1.33
Hyperactivity	1.12 †	0.99	1.25	1.04	0.91	1.19	1.28 *	1.07	1.54
Low prosocial behaviour	1.11 *	1.00	1.23	1.24 *	1.06	1.45	0.98	0.85	1.12
Peer problems	0.97	0.89	1.05	0.81	0.59	1.11	1.02	0.90	1.15

† $p = .06$
* $p < .05$
Note: Model controls for age, ethnicity (white, non-white), exposure to second-hand smoke, household income, household education level, BMI, blood lead and urinary creatinine, and time of urine collection. Significant results indicate change in odds for behavioural outcome associated with a twofold increase in urinary BPA concentration.
Source: 2007/2009 and 2009/2011 Canadian Health Measures Survey (combined).

Sensitivity analyses included testing the multivariate regressions with and without blood lead, with and without BPA outlier cases (above the 99th percentile, or > 22.0 µg/L, n = 26), with and without child age (which was highly correlated with creatinine, $r = .73$, $p \leq .05$), and with and without creatinine. Significant results for hyperactivity and prosocial behaviour persisted in these models. An interaction between age group (6 to 11 and 12 to 17) and BPA concentration was explored, but no significant associations were found. Associations between BPA concentration and hyperactivity were similar when cut-points for at-risk behaviour were determined using sex-specific Goodman[30] values rather than the data-driven norms; the sample size was inadequate to examine prosocial behaviour.

For children aged 6 to 11, separate multivariate models were examined to investigate associations between behavioural outcomes and maternal age at childbirth ($M = 29$ years, $SE = .38$), birthweight ($M = 3{,}377$ g, $SE = 27.12$), and maternal smoking during pregnancy ($n = 241$, 16%). Again, models controlled for sex, ethnicity, household income, and household education. Maternal smoking was significantly associated with conduct problems ($p \leq .01$), hyperactivity ($p = .04$), and total behavioural problems ($p \leq .001$). Maternal age was negatively associated with emotional problems ($p = .03$). No associations were found between birthweight and any of the behavioural outcomes. BPA concentration was not significantly associated with any of the outcomes in these analyses (possibly because of smaller sample sizes or stronger associations between behaviour and the included covariates), although estimates for hyperactivity and prosocial behaviour were in the same direction as in the full analysis.

Discussion and limitations

Consistent with earlier research,[5,6] the current study found that urinary BPA levels differed based on demographic and socioeconomic characteristics, with younger children, those exposed to second-hand smoke, and those in lower income households having higher concentrations.

The CHMS data reveal a link between childhood concentrations of BPA and behaviour, similar to recent findings of Harley et al.[9] and Hong et al.[4] Other research did not find significant associations between childhood BPA exposure and behaviour,[14,18] possibly because of small sample sizes or specific circumstances in a given population (for example, a low-income Hispanic sample[9]). Even in studies linking lead exposure (a commonly studied neurotoxin) and behaviourial outcomes, results are often inconsistent.[36]

In the current study, BPA concentration was positively associated with lower prosocial behaviour in boys and greater hyperactivity in girls, even after considering control variables such as exposure to second-hand smoke and household income. Although the correlations were relatively weak, even a minor association may have public health relevance and warrants further investigation.[13] A small effect at the population level can translate into a substantial number of children and youth at risk for behavioural difficulties.

The sources and pathways of exposure remain subjects for further investigation. BPA can be found in the air, on surfaces, and in liquid and solid foods.[38] Morgan et al.[39] reported that solid (versus liquid) food was a significant predictor of children's dietary intakes of BPA, likely via packaging and containers. Cao et al.[40] suggested that the primary dietary source of BPA is can coating.

What is already known on this subject?

- Bisphenol A (BPA) is a synthetic industrial chemical commonly used in consumer products.
- More than 90% of children and youth aged 6 to 19 have detectable levels of urinary BPA.
- Childhood concentration levels of BPA have been linked with behavioural outcomes.

What does this study add?

- Younger children, those exposed to second-hand smoke every day or almost every day, and those in lower income families had higher urinary BPA concentrations.
- BPA levels were associated with hyperactivity in girls and lower prosocial behaviour in boys.

Children may be particularly vulnerable to the effects of BPA due to their developing brains, close interaction with their environments, lower body weight, and immature body systems.[31] BPA may influence endocrine functioning[41,42] and early structural and functional brain processes.[34] BPA may affect dopaminergic pathways, which play a role in anxiety, hyperactivity and inattention.[9,43] These mechanisms warrant further exploration.

The current study has a number of limitations. A single urine sample taken at the same time as the outcome of interest (cross-sectional data) is limited as a basis for making conclusions about associations between BPA exposure and health outcomes.[3] Moreover, the CHMS data cannot address early or ongoing long-term exposure to BPA, or in-utero exposure. Information on maternal smoking in pregnancy was not collected for the entire age range of the sample. Finally, although parental reports of children's behaviour are commonly used as markers of early risk, data from other sources (for example, teachers) need to be explored.

Conclusion

This is the first large, population-based analysis of associations between BPA concentration in Canadian children and youth and behavioural outcomes. It provides evidence of associations between urinary BPA concentration and children's socioeconomic conditions and their behavioural outcomes. Although cross-sectional, the findings suggest that younger children, those exposed to second-hand smoke every day or almost every day, and those in low-income households have higher urinary BPA concentrations. Inaddition, BPA levels were associated with hyperactivity in girls and lower prosocial behaviour in boys. Further research on Canadian children's exposure to BPA is necessary to understand the mechanisms by which it may be related to behavioural outcomes. Future studies might consider prenatal exposure in concert with childhood concentrations, other indices of child and youth well-being, and exposure to other compounds. ■

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